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No large mass-to-surface area (M/SA) data base exists which can be used as a reference standard to interpret previous or future M/SA studies. This report presents the M/SA data of a large military cohort (1170 males aged 17-54 yr, 305 females aged 17-40 yr). The effects of gender, race and age on distribution of M/SA and other physical characteristics were described. The theoretical value of M/SA as an index of heat tolerance was described in detail. Recommendations for future studies were presented, as well as criticisms of previous studies.

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The Mass-to-Surface Area Index of Heat Tolerance in a Large Cohort

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Running Head: Mass-to-Surface Area Index and Heat Tolerance

[5 tables, 2 figures]

The Mass-to-Surface Area Index of Heat Tolerance in a Large Cohort

Abstract

No large mass-to-surface area (M/SA) data base exists which can be used as a reference standard to interpret previous or future M/SA studies. This report presents the M/SA data of a large military cohort (1170 males aged 17-54 yr, 305 females aged 17-40 yr). The effects of gender, race and age on the distribution of M/SA, as well as the relationship between M/SA and other physical characteristics, were described. It was observed that the increases of M/SA with increasing age (over the 17-25 yr category) were not significant. All descriptive characteristics (including M/SA) were different ($p<.001$) between males and females. M/SA was not statistically different between racial groups, in both males and females. For the first time, two step-wise multiple linear regression equations were presented which allow accurate prediction of M/SA (both $r^2 = .99$) in males and females, using only height and body mass as the dependent variables; these equations were as follows. Males: M/SA ($kg \cdot m^{-2}$) = 45.401 + (0.294 * M) - (0.161 * H). Females: M/SA ($kg \cdot m^{-2}$) = 42.333 + (0.346 * M) - (0.164 * H). Recommendations for future studies and criticisms of subject selection in previous studies, which did not have the benefit of this data base during the process of subject selection, are presented.

KEY WORDS: body composition, height, weight, fat-free mass, age, race, gender, rectal temperature, heart rate, hyperthermia, heatstroke

Introduction

In 1941, Winslow and Gagge (34) reported that a large man dissipated more heat than a small man in a warm-humid environment (21°C, 40-50% rh) because body size played an important role in determining the magnitude of radiant heat dissipation. One year later, Robinson (22) expressed body morphology in terms of body mass per square meter of skin surface area (M/SA), realizing that the heat exchange process was multi-faceted. Two male subjects ran or walked up a grade on a motor driven treadmill in a hot-wet environment of 32°C, 70% relative humidity (rh). The exercise efficiencies of these two men were the same, but the M/SA index of the large man ($44 kg \cdot m^{-2}$) was 20 per cent greater than that of the small man ($35 kg \cdot m^{-2}$), and heat storage was strongly influenced by their M/SA values. These two studies spawned many subsequent physiological investigations (4,7,11,12,16, 20,21,25,26,27,31,32) which described the role between M/SA and heat storage/dissipation. These investigations were especially relevant because hyperthermia (a) is a primary indicator of heat intolerance, (b) results in reduced physical and mental performance--independent of body hydration status, and (c) is the major danger to health during heatstroke. In addition, several researchers suggested that the calculation of M/SA provided a theoretical means to identify individuals who were susceptible to heat injury (3,6,11,22,25,31,32).

A large M/SA index indicates that either fat-free mass or per cent body fat are large in relation to surface area. Both factors have been linked to increased physiological strain during exercise-heat exposure. Fat-free mass was found to be highly correlated with heat strain, in males acclimatizing to dry heat (6). Wyndham (35) calculated that four factors distinguished heat intolerant male laborers from normal laborers; one of these was a body mass

which exceeded their ideal weight by more than 5kg. In two independent studies, obese females (7) exhibited greater physiological strain, and obese males stored more heat, following exercise-heat stress because of their high M/SA index and greater metabolic cost of performing a given task (18).

Skin surface area affects heat dissipation differently in hot-dry and hot-humid conditions (26). This means that M/SA and heat tolerance may not be strongly related in all environments. For example, the computer simulation of Austin and Lansing (4) demonstrated that human heat storage during exercise increased as M/SA increased, but only in environments ranging from 30°C, 80% rh to 45°C, 80% rh. In hot-dry environments, Shvartz et al. (26,27) reported that M/SA was not highly correlated with rectal temperature (Tre) during exercise. In hot-humid environments, most investigations have shown a strong correlation between M/SA and heat tolerance. The temperature difference between skin and air is also an important factor. When skin temperature (e.g. 36°C) is greater than ambient temperature, individuals with low M/SA values dissipate heat faster (via radiation, convection and evaporation) than those with high M/SA values (5,16,22,26). When ambient temperature exceeds skin temperature, a small M/SA apparently is not beneficial because the relatively high surface area available for evaporative cooling is offset by a larger heat gain via radiation and convection (5,16,26).

The anthropological relationship between human morphological variation and climate was first introduced by Schreider in 1950 (24). His data, which suggested racial and gender effects on M/SA, resulted in noteworthy research in recent years. These studies attempted to support or challenge the hypothesis that M/SA decreases as the mean annual temperature of the environment increases. A variety of racial and ethnic groups were evaluated,

including inhabitants of the United States (19), West-Central Africa (17), Zaire (3), Israel, Europe, North-Central Africa, and the Orient (8). Although some of these studies supported Schreider's hypothesis, a series of laboratory studies by Wyndham and colleagues found racial and ethnic factors to be unimportant (26).

Clearly, further research must be conducted to clarify the relationships between M/SA and hyperthermia, heat tolerance, anthropological factors, and environmental factors. Unfortunately, it is difficult to compare and interpret previous studies because they have involved small samples. No large data base exists which can be used as a reference standard for M/SA studies. Therefore, the purpose of the current investigation was to provide a large data base which can be used to interpret the M/SA values of healthy subjects, aged 17 - 54 yr (males) and 17 - 40 yr (females). This report presents data on a total of 1475 (1170 males, 305 females) active duty personnel from a variety of units and assignments in the U.S. Army. The Army is a suitable population for a comprehensive assessment of M/SA because of its broad representation of the national population, as well as its accessibility. Because this investigation utilized a large heterogeneous sample, an analysis of the influences of gender, age and race on M/SA is included, as well as the first normative description of those individuals who are at greatest risk of hyperthermia and heat illness. In addition, these data were utilized to derive an accurate, streamlined method of calculating the M/SA index for males and females, using only the independent variables of height and body mass; this procedure eliminated the intermediate step of calculating surface area, after DuBois and DuBois (10).

Methods

Anthropomorphic and physical fitness data were obtained from a sample of 1475 U.S. Army officers and noncomissioned officers at Fort Hood, Texas and Carlisle Barracks, Pennsylvania. Subject medical records were reviewed, and a physical examination was administered prior to participation, in most cases. Those who were free of significant disease or debilitating orthopedic injuries were utilized for this investigation. Informed voluntary consent was obtained from all subjects. Observations were conducted in accordance with the human experimentation policy statement of the American College of Sports Medicine and the local Human Use Review Committee.

The following values were incorporated into this data base: gender, race, height (H), body mass (M), per cent body fat (%BF), fat-free mass (FFM), maximal aerobic power, and 2-mile run time recorded as a part of the Army Physical Readiness Test. Standard statistical analyses were performed by computer, using commercial statistical software (BMDP, Los Angeles, California). The racial and ethnic categories were based on those suggested by Wallman and Hogdon (33). Due to relatively small sample sizes, races other than white or black were combined in the category named other. Age categories were chosen which would be both physiologically meaningful and which would encompass an adequate sample size. Any gender, age or race category with less than 29 subjects was eliminated from the data base.

Aerobic power was measured as maximal oxygen uptake (VO_2max) using a continuous incremental treadmill test adjusted for sex, age, and activity level. Subjects aged 17-34, and physically active subjects aged 35-39, ran to exhaustion as the treadmill grade increased 2.5% every 3 min (maximum of 15%); treadmill speed was increased by 0.2 $m \cdot s^{-1}$ every 3 min from the initial speeds of 2.6 $m \cdot s^{-1}$ (males) and 2.2 $m \cdot s^{-1}$ (females). Inactive subjects aged

35-39, and all subjects aged 40 and older, underwent trials which began at 1.5 $m \cdot s^{-1}$ and 0% grade; the treadmill grade increased 2.5% every 3 min to a maximum of 15%. If necessary, the test was then continued at 2.6 $m \cdot s^{-1}$ and 0% grade, and the grade increased 2.5% every 3 min.

During body composition measurements, all subjects were measured by the same investigators, using the same techniques. Body mass and height were measured on a platform balance (Sauter Inc., nearest 0.1kg) and by standing against a pre-measured wall ruler (nearest 0.1cm), respectively. Body density and %BF were estimated using an underwater weighing procedure similar to that of Goldman and Buskirk (14), as described by Fitzgerald (13). A desktop computer (Hewlett-Packard, model 85) sampled underwater weight every 10-15 seconds, calculating body density according to the formula of Buskirk (9) and %BF according to the formula of Siri (28). SA was calculated by using height and body mass values, according to the formula of Du Bois and DuBois (10). Both FFM and M/SA were calculated and incorporated into the data file. To compare M/SA among sub-samples, subjects were categorized by sex, age, and race, and the 95% confidence limits (mean $\pm$ 2SD) were calculated. Descriptive characteristics for all males and all females were expressed separately, and in the following three M/SA sub-samples: SMALL (subjects with M/SA smaller than - 2SD of the mean), LARGE (subjects with M/SA larger than + 2SD of the mean), and AVERAGE (subjects with M/SA within $\pm$ 2SD of the mean).

Two step-wise multiple linear regression equations were computed to predict M/SA. All descriptive characteristics (Table 1) were used as dependent variables, but only M and H were significantly related and retained. The data from all males and females, regardless of age and race, were used in these regression analyses.

Results

Table 1 presents the descriptive characteristics of the males and females who participated in this study (all ages, all races). Portions of these results have been published elsewhere (13,30). Statistically significant ($p<.001$) differences between males and females existed in all characteristics presented in Table 1. The 95% confidence limits for male M/SA were 34.0 - 45.6kg$\cdot$m^{-2}, and were 31.7 - 41.3kg$\cdot$m^{-2} for female M/SA.

Figures 1 and 2 show the M/SA distribution for all males and all females, respectively. The mean ($\pm$ SD) M/SA for all males and females were 39.8 $\pm$ 2.9 and 36.5 $\pm$ 2.4kg$\cdot$m^{-2}, respectively.

Both multiple linear regression equations to predict M/SA accounted for 99% ($r^2 = 0.99$) of the variability by using only H (cm) and M (kg) as independent variables, and were significant at the $p<.001$ level. These equations took the form shown below for males (Eq. 1) and females (Eq. 2).

Males

$$M/SA\ (kg\cdot m^{-2}) = 45.401 + (0.294 * M) - (0.161 * H) \qquad \text{(Eq. 1)}$$

Females

$$M/SA\ (kg\cdot m^{-2}) = 42.333 + (0.346 * M) - (0.164 * H) \qquad \text{(Eq. 2)}$$

For the first time, M/SA may now be calculated from H and M without the intermediate determination of surface area from equations or tables (10).

Table 2 presents the mean ($\pm$ SD) M/SA of males and females, categorized by age and race. The increases of M/SA with increasing age (over the 17-25 yr category) were not significant. M/SA was statistically similar between racial groups, at all ages, in both males and females. However, black males (all ages) had a lower percent body fat ($p<.001$, not shown) and higher FFM ($p<.001$, not shown) than white or "other" males.

Tables 3 and 4 present descriptive characteristics of males and females in the following three groups: SMALL (subjects with M/SA smaller than - 2SD of the mean), LARGE (subjects with M/SA larger than + 2SD of the mean), and AVERAGE (subjects with M/SA between - 2SD and + 2SD). In nearly every instance, the values of males and females (Tables 3 and 4) predictably increased from SMALL to AVERAGE to LARGE. But, LARGE individuals were not significantly older than SMALL or AVERAGE individuals. It is also noteworthy that SMALL males and females tended to have a higher VO_2max, expressed in $ml \cdot kg^{-1} \cdot min^{-1}$, than LARGE and AVERAGE males and females, in spite of a lower VO_2max expressed in $L \cdot min^{-1}$. SMALL males and females also completed the 2-mile run in less time than AVERAGE and LARGE.

Discussion

Future research is required to clarify the relationships between M/SA and hyperthermia, heat tolerance, environmental factors, and anthropological factors. Unfortunately, most previous M/SA studies (Table 5) involved small sample sizes, young adults, and subjects of unspecified racial origin. It is clear that few researchers have considered the effects of age, gender and race on M/SA. Further, none of the studies summarized in Table 5 utilized normative data in their design. The present investigation presented M/SA values, of the largest and most diversified sample of the United States population to date, by which the M/SA of males and females can be interpreted.

Had previous investigators (Table 5) utilized the present data base, their interpretation of results may have been different. For example, Israeli investigators (11) compared former heatstroke patients with normal control (C)

subjects during a heat-tolerance test (bench stepping, 180 min, 12 steps$\cdot$min^{-1}, 30cm high, 40^{o}C/40%rh). The heatstroke patients were divided into two sub-samples: heat intolerant (HI) and normal thermoregulation (NT). The authors indicated that two variables, M/SA and exercise efficiency, statistically distinguished HI from C. However, the M/SA of HI (40.5kg$\cdot$m^{-2}), NT (36.8kg$\cdot$m^{-2}), and C (36.7kg$\cdot$m^{-2}) were similar to the mean M/SA of all males in our sample (39.8kg$\cdot$m^{-2}, n = 1170, Table 1), and fell within the 95% confidence limits for male M/SA.

THE 95% CONFIDENCE LIMITS

Similarly, the studies summarized in Table 5 rarely focused on males and females who had M/SA values outside our 95% confidence limits. Out of the 32 mean M/SA values presented in Table 5, only 2 female and 2 male groups were less than - 2SD and only 1 female and 1 male group were greater than + 2SD from the mean (Table 1). In addition, only 7 (1 female, 6 male) out of 32 groups reported M/SA which were above the gender-appropriate mean of our sample (Figures 1 and 2). This means that the subjects tested in most previous studies were probably not those at greatest risk of heat injury, and that future studies should focus on males and females who lie outside the 95% confidence limits defined in the current investigation. Many studies have emphasized the increased risk of hyperthermia and heat illness in humans who have extremely low or extremely high M/SA indices, and explain the purpose of Tables 3 and 4. The sub-samples LARGE and SMALL in Tables 3 and 4 represent groups of humans who, theoretically, are at increased risk of incurring heat illness (see below). Comparison of the characteristics listed in Tables 3 and 4, therefore, provides insight into intra-individual differences in heat tolerance.

The significance of extremely small stature has been reported in previous studies (3,29,31). Austin and Ghesquiere (3) examined the impact of extremely small stature ($33.4 kg \cdot m^{-2}$) on heat tolerance in African Pygmoids. They reported that Tre and heart rate (HR) were significantly higher in Pygmoids than in African Bantu males ($35.5 kg \cdot m^{-2}$), and concluded that this was due to their extremely small stature, rather than differences in heat acclimatization or exercise capacity. Wagner et al. (31) also focused on small body dimensions, by evaluating prepubertal boys ($30.7 kg \cdot m^{-2}$). The authors concluded that these boys were unable to regulate body temperature as well as postpubertal boys or men, because of their lower evaporative cooling capacity (e.g. smaller M/SA and lower sweat rate). SMALL males (Table 3) had a VO_2max of 2.688 $L \cdot min^{-1}$. This value is similar to the data published by Strydom in 1980 (29), which reported the mean VO_2max of 19 heat intolerant males as 2.42 $L \cdot min^{-1}$. Further, Strydom described the impact of low body weight on the heat tolerance of miners. Unacclimatized men with body mass of less than 50kg (n = 23) were at greater risk of developing heatstroke than unacclimatized men of normal body mass. This 50kg body mass was similar to SMALL males in the current investigation (53.6kg, Table 3). Thus, the heat tolerance of our SMALL sub-sample was theoretically less than AVERAGE, because of their extremely small stature.

The significance of extremely large stature has been supported by a variety of previous studies (2,7,18,23,26,32). Wailgum and Paolone (32) investigated football linemen who had large M/SA indices ($45.5 kg \cdot m^{-2}$). These males were found to be at greater risk of hyperthermia than football backs ($41.7 kg \cdot m^{-2}$), particularly while wearing uniforms in humid environments. Miller et al. (18) tested the heat tolerance of 14 obese males ($50.1 kg \cdot m^{-2}$), while Bar-Or (7) tested 5 obese females ($45.9 kg \cdot m^{-2}$). Both research teams

concluded that obese subjects exhibited inferior performance because of slower dissipation of stored heat, resulting from their high M/SA index. Schickele (23) reported that heatstroke was more likely to lead to death in patients with large M/SA indices. Also, a recent case report (2) monitored a 32 year-old male (180cm height, 110.47kg body mass) who exhibited heat intolerance (days 5 - 8) and heat exhaustion (day 8) during an 8-day heat acclimation study. The M/SA index of this subject was extremely large (48.0kg$\cdot$m^{-2}), when compared to 13 other males (mean: 40.4kg$\cdot$m^{-2}) who completed the heat acclimation regimen without difficulties. Other studies have observed that low cardiovascular physical fitness, low exercise efficiency, high metabolic heat production, and the low specific heat of adipose tissue are critical factors in the onset of hyperthermia in obese individuals (7,26,32). LARGE males in the current investigation had a mean %BF of 30.2%, compared to 20.1% and 16.2% for AVERAGE and SMALL, respectively (Table 3). This large %BF in LARGE probably increased the tissue weight which could not utilize oxygen for muscular contraction, reduced exercise efficiency, and had a negative motivational effect on the amount of habitual participation in aerobic training (30). Thus, the heat tolerance of our LARGE sub-sample was theoretically less than AVERAGE (Tables 3 and 4), because of their extremely large stature.

AGE, RACE, AND GENDER EFFECTS

Intuitively, one might expect that M/SA might increase as age increases, but all males and females in Table 2 had similar M/SA values, regardless of their age category. The effect of race was also minimal. Males and females in these age categories (Table 2) had similar M/SA indices. When compared to males of other nationalities, the current data base indicated the following: (a) African Bantu and Pygmoid males (3) and 69 other African samples (17)

had M/SA indices below the mean of U.S. males (Table 1); (b) 60 Oriental males (8) fell approximately - 1SD from the mean of U.S. males; and (c) East-European males (8) averaged virtually the same M/SA as U.S. males in the present investigation. Differences in heredity, nutrition and activity, which affect %BF and FFM, probably explain these international M/SA differences.

The effect of gender on M/SA index was significant (Table 1), however. All female characteristics were smaller ($p<.001$) than those of males, except %BF and 2-mile run time, which were significantly larger ($p<.001$). The smaller M/SA index of females previously has been reported as a beneficial factor in hot, humid environments, evidenced by lower HR and Tre during exercise than males (5,20,25). But, when matched for M/SA (5,25) and VO_2max (5,20), there were no significant differences in HR or Tre between the sexes. The fact that the mean M/SA index of AVERAGE females differed from AVERAGE males (Tables 3 and 4) by a minor amount (9.2%), suggests that M/SA may not influence heat tolerance significantly in these two sub-samples.

In conclusion, the three salient applications of the current investigation are as follows. First, normative M/SA data have been presented by which previous and future studies may be interpreted. This normative data is valuable because some previous studies have attributed intra-group heat tolerance differences to M/SA differences, when other factors (e.g. cardiovascular physical fitness, heat acclimatization status) may have influenced heat tolerance more than M/SA. The current data base indicates that these intra-group M/SA differences were small (i.e. 33.4 vs 35.5, 35.9 vs 37.9, 35.7 vs 38.7, 35.8 vs 38.8 $kg \cdot m^{-2}$) (3,5,11,15,21), and did not include subjects who were most likely to be heat intolerant (e.g. M/SA values outside the 95% confidence limits of subjects in the current investigation) (7,11,26,32). This

normative data also may be utilized to compare M/SA values of U.S. citizens with those of other racial and ethnic groups. Second, the males and females who are likely to have the greatest risk of heat intolerance (2,3,7,18,23,26,29,31,32) have been described. Those humans whose M/SA approximates the SMALL or LARGE sub-samples (Tables 3 and 4) may now be identified in groups of athletes, laborers or soldiers. If future research verifies that SMALL and LARGE sub-samples have reduced heat tolerance, these males and females may be eliminated objectively, or monitored closely, when performing tasks which involve strenuous exercise and either hot-humid environments or impermeable clothing. Third, accurate equations to calculate M/SA have been presented for U.S. males (aged 17 - 54 yr) and females (aged 17 - 40 yr) which utilize H and M values. These equations correlated significantly ($p<.001$, $r^2 = 0.99$) with the previous method, which involved calculating surface area as an intermediate step.

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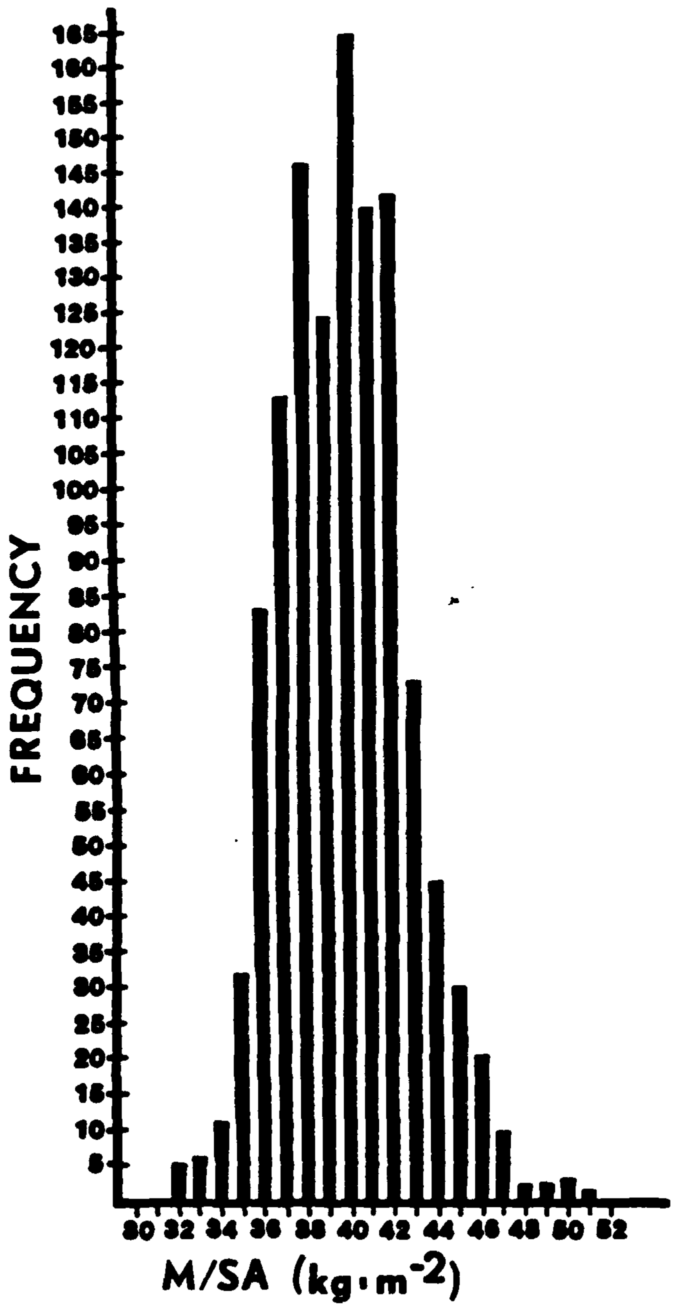
Figure Titles

Figure 1 - Frequency distribution of M/SA for all males ($n = 1165$). The mean ($\pm$ SD) M/SA value was 39.8 ± 2.9 $kg \cdot m^{-2}$.

Figure 2 - Frequency distribution of M/SA for all females ($n = 303$). The mean ($\pm$ SD) M/SA value was 36.5 ± 2.4 $kg \cdot m^{-2}$.

Figure 1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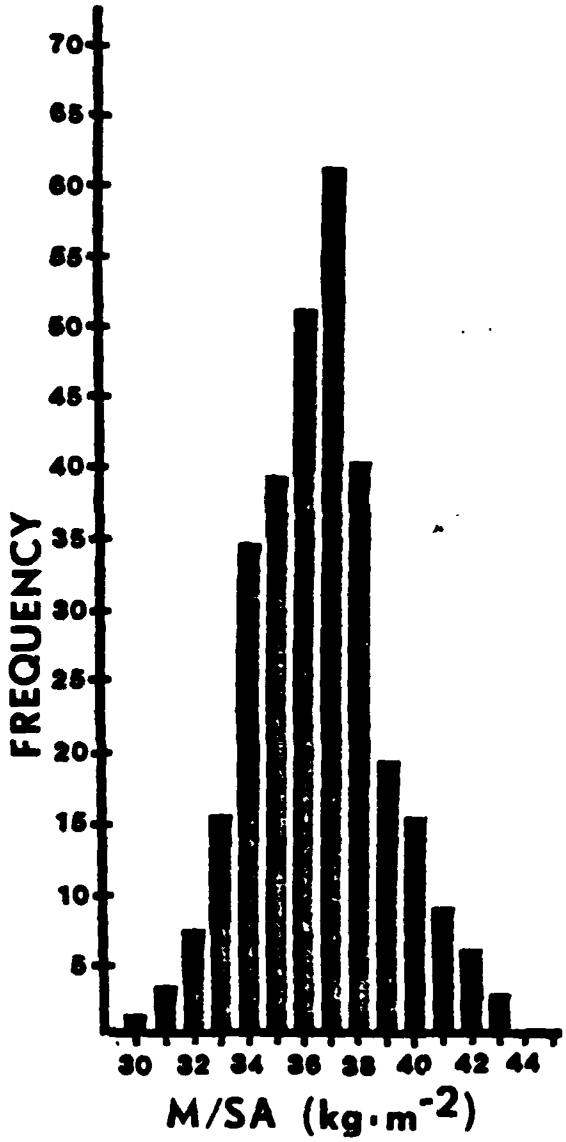
M/SA (kg·m-2)

Figure 2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M/SA (kg·m-2)

Table 1 - Descriptive characteristics of all male and female subjects. All characteristics were significantly different (males vs females) at the $p<.001$ confidence level.

Characteristic (unit)		Males			Females		
		n	Mean	$\pm$ SD	n	Mean	$\pm$ SD
Age	(yr)	1170	30.2	8.8	305	24.0	5.0
H	(cm)	1165	175.1	6.9	303	162.4	6.4
M	(kg)	1165	76.8	11.3	303	59.9	8.0
SA	(m^2)	1165	1.9	0.2	303	1.6	0.1
M/SA	($kg \cdot m^{-2}$)	1165	39.8	2.9	303	36.5	2.4
%BF	(%)	1153	20.3	6.7	289	27.3	5.6
FFM	(kg)	1153	60.8	7.4	289	43.3	5.0
VO_2max	($ml \cdot kg^{-1}\ min^{-1}$)	780	47.644	6.170	265	39.257	4.469
VO_2max	($L \cdot min^{-1}$)	780	3.566	0.494	265	2.331	0.322
2-mile run	(min)	1046	14.58	2.04	289	17.48	2.22

Table 2 - M/SA ($kg \cdot m^{-2}$) categorized by gender, race and age.

Sex	Race	Age Group	n	M/SA mean	M/SA ± SD
m	black	17 - 25	116	38.9	2.5
m	black	26 - 34	108	39.9	3.2
m	black	35 - 39	31	40.9	3.2
m	white	17 - 25	255	38.9	2.6
m	white	26 - 34	149	40.4	3.0
m	white	35 - 39	76	41.0	3.3
m	white	40 - 49	227	40.6	2.2
m	other*	17 - 25	57	38.3	3.0
m	other*	26 - 34	71	39.9	3.0
m	other*	35 - 39	31	40.6	3.5
f	black	17 - 25	83	36.2	2.1
f	black	26 - 34	29	37.4	2.1
f	white	17 - 25	106	36.0	2.2
f	white	26 - 34	42	37.4	3.1

* - other includes the following races: Hispanic, Alaskan/Native American, Asian/Pacific Islander

Table 3 - Comparison of male descriptive characteristics of three M/SA sub-samples: SMALL (n = 19), AVERAGE (n = 1112), LARGE (n = 34).*

Characteristic	(unit)	SMALL		AVERAGE		LARGE	
		mean	± SD	mean	± SD	mean	± SD
Age	(yr)	28.9	9.0	30.4	9.0	31.7	7.5
H	(cm)	170.1	6.0	175.1	6.9	179.4	6.9
M	(kg)	53.6	3.9	76.3	9.8	106.8	8.8
SA	(m^2)	1.6	0.1	1.9	0.1	2.3	0.1
M/SA	($kg \cdot m^{-2}$)	33.2	0.8	39.7	0.2	47.4	1.4
%BF	(%)	16.2	5.5	20.1	6.5	30.2	4.7
FFM	(kg)	44.9	4.7	60.7	6.6	74.5	8.4
VO_2max	($ml \cdot kg^{-1} \cdot min^{-1}$)	50.049	5.595	47.912	6.018	38.360	2.548
VO_2max	($L \cdot min^{-1}$)	2.688	0.472	3.570	0.472	4.081	0.429
2-mile run	(min)	14.53	2.11	14.55	2.04	17.08	1.50

* - SMALL: subjects with M/SA smaller than - 2SD of the mean

AVERAGE: subjects with M/SA within ± 2SD of the mean

LARGE: subjects with M/SA larger than + 2SD of the mean

Table 4 - Comparison of female descriptive characteristics of three M/SA sub-samples: SMALL (n = 8), AVERAGE (n = 286), LARGE (n = 9).*

Characteristic (unit)		SMALL		AVERAGE		LARGE	
		mean	± SD	mean	± SD	mean	± SD
Age	(yr)	25.0	7.0	24.0	5.0	28.0	3.0
H	(cm)	159.9	2.6	162.4	6.3	165.0	10.8
M	(kg)	45.0	1.5	59.6	6.9	78.9	7.9
SA	(m^2)	1.4	0.3	1.6	0.1	1.9	0.2
M/SA	($kg \cdot m^{-2}$)	31.4	0.6	36.4	2.0	42.3	0.6
%BF	(%)	21.5	7.5	27.3	5.3	33.3	7.5
FFM	(kg)	35.4	4.7	43.7	6.7	53.7	8.4
VO_2max	($ml \cdot kg^{-1} \cdot min^{-1}$)	41.000	5.329	39.420	4.345	34.125	3.563
VO_2max	($L \cdot min^{-1}$)	1.858	0.296	2.330	0.300	2.725	0.525
2-mile run	(min)	18.14	2.04	18.43	2.20	19.46	2.17

* - SMALL: subjects with M/SA smaller than - 2SD of the mean

AVERAGE: subjects with M/SA within ± 2SD of the mean

LARGE: subjects with M/SA larger than + 2SD of the mean

Table 5 - Summary of previous physiological investigations which evaluated M/SA as an index of heat tolerance.

investigation, year (ref.)	n male	n female	age (yr) mean (± SD)	race	M/SA ($kg \cdot m^{-2}$) mean (± SD)	notes
Armstrong et al., 1987 (2)	14		28.4 ± 7.1	white	40.4 ± 3.6	
Austin et al., 1976 (3)	10		*	black	35.5 ± *	African Bantu
	10		*	black	33.4 ± *	African pygmoid
Avellini et al., 1980 (5)	4		24.0 ± 4.2	*	38.5 ± *	matched for VO_2max with females
		4	23.5 ± 1.9	*	35.8 ± *	matched for VO_2max with males
Bar-or et al., 1969 (7)		5	19.0 ± 1.2	*	45.9 ± 2.8	obese
		4	21.2 ± 1.0	*	34.0 ± 0.8	lean
Epstein et al., 1983 (11)	5		23.5 ± 8.3	*	40.5 ± *	heatstroke, heat intolerant
	9		20.5 ± 6.9	*	36.8 ± *	heatstroke, normal tolerance
	9		19.1 ± 3.9	*	36.7 ± *	healthy controls
Fein et al., 1975 (12)		6	22.3 ± 2.5	*	36.5 ± 1.7	students
		6	21.1 ± 3.2	*	36.4 ± 2.8	students
Haymes et al., 1974 (16)		5	10.2 ± 0.9	*	28.4 ± *	lean, prepubertal
		7	10.1 ± 0.8	*	32.6 ± *	obese, prepubertal
Miller et al., 1958 (18)	14		23.8 ± *	*	38.9 ± *	normal students
	14		20.5 ± *	*	50.1 ± *	obese students
Pivonka et al., 1963 (22)	7		22.6 ± 1.1	*	38.7 ± 3.0	untrained
	5		21.2 ± 4.1	*	35.7 ± 0.8	collegiate runners
Robinson, 1942 (23)	2		22 - 24 +	*	35 - 44 +	
Shapiro et al., 1980 (26)		9	22.0 ± 3.0	*	35.6 ± *	soldiers
	10		21.1 ± 1.9	*	39.2 ± *	soldiers
Shvartz et al., 1973 (27)	25		23.0 ± 3.5	white	38.6 ± *	
	8		22.0 ± 3.4	white	39.2 ± *	
Shvartz et al., 1977 (28)	7		19.7 ± 1.3	*	37.2 ± *	trained
	7		21.3 ± 1.5	*	38.2 ± *	untrained
	7		19.0 ± 0.6	*	37.6 ± *	unfit
	5		20.4 ± 2.7	*	37.7 ± *	control subjects
Wailgum et al., 1984 (33)	4		22.0 ± 0.8	*	45.5 ± *	football linemen
	4		22.0 ± 2.6	*	41.7 ± *	football backs
Wagner et al., 1972 (32)	10		20 - 29 +	*	39.5 ± *	young men
	7		46 - 67 +	*	40.7 ± *	older men
	5		11 - 14 +	*	30.7 ± *	prepubertal
	5		15 - 16 +	*	34.4 ± *	postpubertal

* - information not available   + - range